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An assessment of alternate keyboards using finger motion, wrist motion and tendon travel

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Abstract

Objective. To assess the biomechanical impact of commercially available alternate keyboard designs.

Design. A repeated measures study was conducted in a laboratory setting, with planned comparisons of Pitch, Roll and Yaw angles of the keyboards. Ten keyboard conditions were tested. Dependent measures included tendon travel, wrist deviations, and wrist and finger kinematics.

Background. Various alternate keyboard designs have recently been introduced, which vary Pitch, Roll and Yaw angles, separation distance between keyboard halves, and include other novel features such as cup-shaped depressions for the keys. Yet little objective research has been conducted regarding the biomechanical implications of these various design features. This study attempts to quantify the keyboard designs in terms of several recognized risk factors associated with cumulative trauma disorders that arise with repetitive typing.

Methods. Wrist and finger goniometers were used to measure joint motions during a standardized typing task. 15 experienced typists (8 women, 7 men) served as subjects. Regression equations were used to generate estimates of tendon travel.

Results. Tendon travel was affected primarily by Pitch but not Roll or Yaw angles while wrist deviations responded to changes in all three angles. Males had significantly greater amount of tendon travel than female subjects; this difference was only partially accounted for by anthropometry. Differences in joint motion may have a greater impact on the amount of tendon travel.

Conclusions. Alternate keyboard designs can affect tendon travel by as much as 11%.

Relevance

As various alternate keyboard designs are marketed, quantifiable biomechanical data such as that provided by this study, will help to assess their impact on the risk factors for cumulative trauma disorders.

Keywords: Alternate keyboards; Cumulative trauma disorders; Tendon travel; Wrist deviations

1. Introduction

Repetitive typing may cause cumulative damage to the flexor tendons of the forearm. To address the risk of injury, alternate keyboard designs have been introduced with novel designs such as negative tilt, split keyboard, or cup-shaped depressions for the keys. Little objective research has been conducted on these alternate designs to assess their biomechanical impact and determine whether the differences between designs are of occupational significance. With no objective criteria or comparisons to the existing keyboard design, there is scant evidence to support their claims of being "ergonomic". A fundamental research question is: What are the biomechanical benefits (or costs) of alternate designs, such as tilting, rotating or splitting the keyboard halves, when compared to the conventional keyboard? The aim of the experiment was to assess some commercial alternate keyboards in terms of known biomechanical stressors.

2. Methods

The experimental design and procedures were essentially the same as that reported in the companion keyboard paper published in this volume [1]. Fifteen subjects (8 women, 7 men), ranging from 21 to 49 years, were tested on the ten keyboard conditions. All were touch typists capable of typing at least 45 wpm with a

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maximal error rate of 5%, and none had experienced upper extremity disorders. The alternate keyboards used in this study are shown in Fig. 1, with the salient characteristics of each keyboard listed in Table 1. Conditions 6 and 7 were included because these conditions produced the lowest amount of tendon travel in the earlier keyboard study. In Condition 10, subjects adjusted one of the keyboards according to their perception of comfort and typing ease. This was done to test how well subjects' perceptions and adjustments reduced biomechanical stressors. Conditions 1–9 were tested in random order and Condition 10 was always tested last.

The Kinesis™ keyboard had the most radical design, with cupped shaped depressions for the keys and different location for keys such as the space bar, back space and delete key, and required training to become familiar with the novel layout. A pilot test with five subjects found that after 1 h of practice on the Kinesis™ keyboard (text only), subjects were able to type at 86% of their baseline typing speed with an error rate $\leqslant 5\%$. Hence, an hour of practice was provided prior to testing to acclimate subjects to the radical design of the Kinesis keyboard. No practice time was provided for the other keyboards.

Dependent variables were tendon travel for the *flexor digitorum superficialis* and *flexor digitorum profundus*, denoted TTFDS and TTFDP respectively. Other dependent variables were wrist deviations in three planes of motion: flexion/extension (F/E), radial/ulnar (R/U), and pronation/supination (P/S); and the joint motion of the metacarpophalangeal (MP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints of the left index finger.

2.1. Planned comparisons

Since the objective of the study was to assess the impact of specific keyboard features, planned comparisons were used to compare the keyboards in terms of Pitch, Roll and Yaw angles. For Pitch comparisons, the two negative Pitch conditions (#2 and 9) were compared to the positive Pitch conditions (#1, 4, 5, 6, and 7). For the Roll comparisons, positive Roll conditions (#1, 2, 6, and 7) were compared to zero Roll conditions (#4, 5, 8, and 9). Positive yaw conditions (#1, 2, and 7) were compared to zero Yaw conditions (#4, 5, 6, 8 and 9).

Conditions 3 and 10 were excluded from these comparisons because they are fundamentally different from the others. Condition 8 was excluded from the Pitch comparisons since it had a zero Pitch and the Pitch comparisons were between positive and negative Pitch, but it was included in the comparisons for Roll and Yaw.

3. Results

3.1. Tendon travel and wrist deviations

Tendon travel responds to changes in Pitch angle, but not to positive Roll and Yaw angles, while wrist deviations respond to changes in all three angles. Negative Pitch keyboards had significantly more tendon travel than positive Pitch ones. This was true for both tendons: the mean tendon travel (standard deviation) for the *superficialis* tendon was 965 (284) and 905 (229) mm for negative and positive Pitch, respectively. For the *pro-*

Fig. 1. Test keyboards: upper left: Microsoft Natural™; upper right: Kinesis™; lower left: standard keyboard; lower right: Lexmark™.

Table 1
Keyboard conditions

Condition	Keyboard	Pitch	Roll	Yaw	Separation distance[a] (in.)
1	Microsoft Natural™ Keyboard	+5°	+8°	+10°	1.5
2	Microsoft Natural™ Keyboard	−3°	+8°	+10°	1.5
3	Kinesis™ Keyboard	NA	NA	NA	6.5
4	Standard Keyboard	+5°	0°	0°	0
5	Standard Keyboard	+11°	0°	0°	0
6	Lexmark™ Keyboard	+25°	+15°	0°	1.25
7	Lexmark™ Keyboard	+25°	+15°	+30°	5.25
8	Lexmark™ Keyboard	0°	0°	0°	0.8
9	Lexmark™ Keyboard	−7°	0°	0°	0.8
10	Lexmark™ Keyboard	Subject adjusts keyboard			

[a] Separation distance between the two halves of the keyboard, measured at home row.

fundus tendon, the values were 939 (275) and 885 (223) mm for negative and positive Pitch, respectively.

3.2. Gender differences

In comparing the average tendon travel for males and females by condition, males uniformly had significantly higher tendon travel than the females. The difference ranged from 2% in Condition 6, to 20% in Condition 2; the average difference between males and females was 10%. Males also showed greater variability in tendon travel across all conditions. Thus, males and females respond differently to the same keyboard condition.

3.3. Anthropometric dimensions

The difference in tendon travel between males and females was hypothesized to be due to differences in hand anthropometry, so covariate analyses were performed to correlate hand size with tendon travel. A small but statistically significant relationship exists between tendon travel and three variables: Hand Length, Distal Phalanx Length, and Wrist Breadth. To determine whether there was a relationship between greater tendon travel and hand anthropometry, these were plotted together as seen in Fig. 2. Here, tendon travel is plotted in ascending order, by subject. Below the tendon travel plots are the hand dimensions, also plotted by the corresponding subject. It can be seen that the increasing trend in tendon travel is not associated with any discernible trend in the hand dimensions. In addition, a comparison was made between the subjects with the greatest (1624 mm) and least (624 mm) tendon travel, which showed that both subjects were males with similar anthropometric dimensions. Anthropometric dimensions can be said to account only generally for the variability in tendon travel.

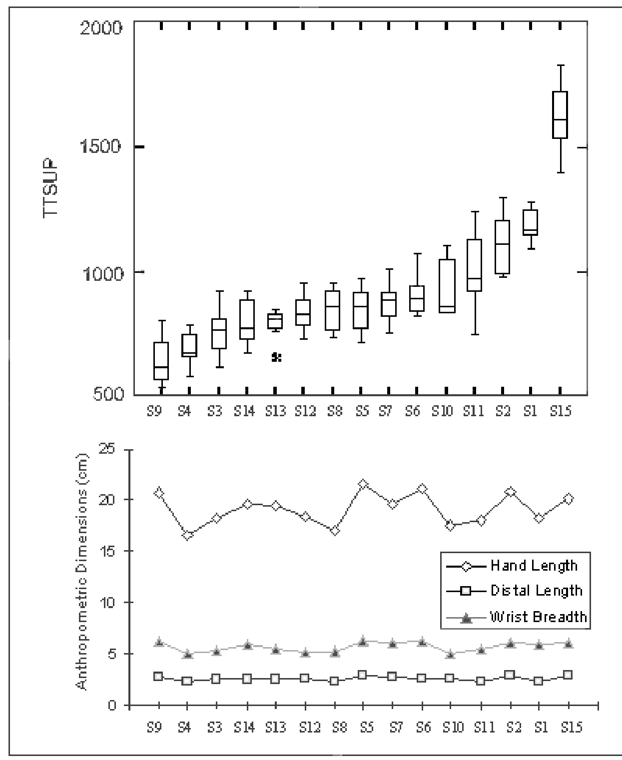

Fig. 2. Box plots of tendon travel and hand anthropometry by subject, in ascending order of tendon travel, with each subject's corresponding hand anthropometric dimensions presented below. Box represents median, 25th and 75th percentile. * = outside value.

3.4. Wrist and finger joint analysis

In order to determine whether anthropometry affected joint motions and the amount of tendon travel, wrist joint (in flexion/extension only) and the three finger joints were analyzed. The three subjects with the smallest hand dimensions were compared to the three with the largest dimensions. Fig. 3 shows this comparison in graphic form. Each of the four joints is represented as a percentage of overall joint angle. This

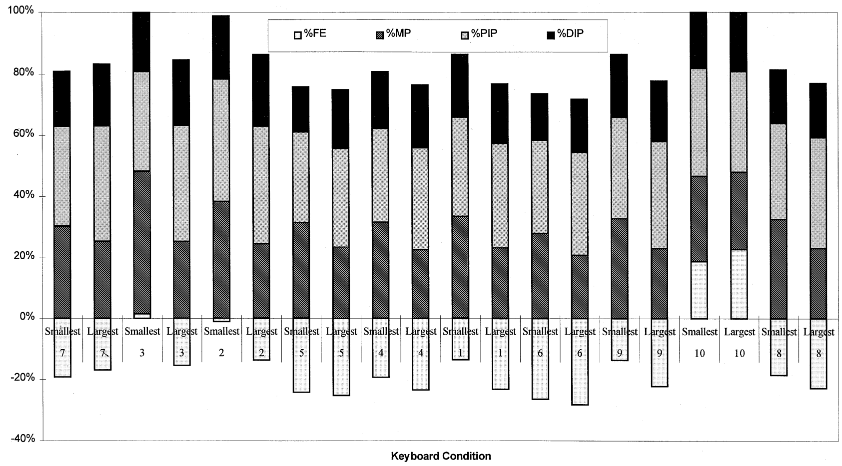

Fig. 3. Analysis of individual joint motion for Smallest and Largest hand sizes, by keyboard condition, arranged in ascending order of TTFDS. Negative values denote extension; positive values denote flexion. Height of shaded region within bars represent the percent contribution to the total hand/finger angle, by individual joint (wrist, MP, PIP, DIP).

allowed us to determine how much each joint contributed to the overall hand/finger position. The group with the largest hand size had more wrist extension and greater total finger flexion than the smallest hand group, predominantly in the PIP and DIP joints. This group also experienced more tendon travel: the mean (standard deviation) for the *profundus* tendon was 955 (55) and 851 (47) mm for large and small hands, respectively. For the *superficialis* tendon, the values were 951 (54) and 822 (42) mm for large and small hands, respectively.

3.5. Kinematic variables

The effect of joint position, velocity, and acceleration on tendon travel was tested with analysis of variance (ANOVA). From these initial analyses, the statistically significant variables were combined into a single model, which is shown in Table 2. This modified model has greater explanatory power than the earlier separate models, accounting for ~95% of the variability in tendon travel. Tendon travel is increased with more wrist extension (or less wrist flexion), or faster MP or PIP velocities.

3.6. Subject adjusted keyboard

Condition 10, the last condition of the experiment, required the subject to adjust the Pitch, Roll and Yaw angles of the Lexmark™ keyboard to the configuration that he/she considered most comfortable. Some subjects choose keyboard angles which reduced the amount of tendon travel by approximately one-third less than that for the standard keyboard. Others choose keyboard angles which increased the amount of tendon travel (in this case, by 28%). It appears that adjustments made on the perception of comfort may produce conflicting results. Users may benefit from more specific guidance on how to adjust the keyboard in order to reduce the level of biomechanical stress.

Table 2
Regression results for modified model for tendon travel of the flexor digitorum superficialis (TTFDS) and flexor digitorum profundus (TTFDP)[a]

	TTFDS		TTFDP	
	F-statistic	*p*-value	*F*-statistic	*p*-value
Gender	5.75	0.0180	6.14	0.0146
Subj(Gender)	29.95	0.0001	30.93	0.0001
Condition	2.43	0.0143	2.44	0.0136
FE-Angle	20.32	0.0001	22.44	0.0001
MP-Velocity	56.97	0.0001	44.46	0.0001
PIP-Velocity	10.08	0.0019	16.32	0.0001
FE-Accel	0.20	0.6562	0.73	0.3935

[a] F/E: wrist flexion/extension; MP: metacarpophalangeal joint; PIP: proximal interphalangeal joint.

4. Discussion

The results of this study show that increasing Pitch (i.e. positive pitch angle) appears to decrease tendon travel. The two negative Pitch conditions produced the greatest amount of tendon travel of all 10 conditions. However, the gender effect seems to indicate that males and females may respond differently to keyboard Pitch angle.

There was a significant gender effect on tendon travel, with males having greater tendon travel than females across all conditions. The Condition × Gender interaction, however, was statistically insignificant. Qualitatively, it can be seen that males and females react differently to the various keyboards. For instance, the negative pitch keyboards, Conditions 2 and 9, show differing results by gender. Condition 2 produced much greater difference in tendon travel between males and females, than did Condition 9 wherein the gender difference is smaller.

The analysis by smallest and largest hand sizes showed that more wrist extension and greater finger flexion are seen in subjects with larger hands. In terms of total joint angle (derived by adding up the angles of all four joints, regardless of flexion or extension for the wrist), large-handed subjects had greater total joint angles and also greater finger angles. Larger hand sizes may have required some kind of accommodation such as extending the wrist while flexing the fingers, whereas smaller hands are able to lie flatter on the keyboard, thus exhibiting less wrist extension and finger flexion. In every condition, the large-handed subjects had more tendon travel than the small-handed group.

One explanation for this difference may lie in the design of the keyboards themselves. The keyboards for Conditions 1, 2 and 3 have a broad flat surface at the front edge that could be used as a wrist rest. Indeed the results support this explanation: the greatest difference in tendon travel between the large hand and small hand groups was seen in these 3 conditions (differences ranged from 18% to 23%). Long-handed users may be more inclined to extend the wrist while curling (flexing) the fingers, thus "fitting" their hands to the keyboard in order to place their wrist on this built-in wrist rest. Users with smaller hands would feel less need to change their wrist/finger angles to fit their hands onto the wrist rest. Since this study was primarily geared towards evaluating the effect of various Pitch, Roll and Yaw angles, these secondary design features (built-in wrist rests) were not explicitly tested, but appear to have an unexpected effect on users' typing posture and movements.

The findings of this study, that greater wrist extension and more finger flexion are associated with more tendon travel, may appear to contradict the findings of the earlier study published in this volume [1]. However, it should be noted that in that earlier study, subjects did not rest their wrists on either the desk or keyboard at any time. Their hands were free to assume any position above the keyboard, whereas in the current study some of the keyboards had built-in wrist rests.

5. Conclusions

The results showed that alternate keyboard designs can affect tendon travel up to ~11% difference. Multiplied over an extended period, this may mean the difference between a high risk and low risk job. The high degree of subject variability in tendon travel may make it difficult to reduce tendon travel solely through the selection of the appropriate keyboard design. Gender appears to have a pronounced effect on tendon travel that is only partially explained by differences in hand anthropometry. A better explanation of the gender differences may be the ways in which the individual joints are used to achieve the needed degree of finger flexion and wrist flexion/extension. Additional research is needed to determine how specific keyboard features interact with hand size, wrist and finger position, and typing style to influence tendon travel.

Acknowledgements

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Reference

[1] Nelson JE, Treaster DE, Marras WS. Finger motion, wrist motion, and tendon travel as a function of keyboard angles. Clinical Biomechanics 2000;15:489–98.